MASSACHUSETTS COASTAL COMMERCIAL LOBSTER TRAP SAMPLING PROGRAM MAY-NOVEMBER, 1995

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ABSTRACT

This is the Massachusetts Division of Marine Fisheries fifteenth annual assessment of the status of the American lobster resource in Massachusetts coastal waters. During the period of May through November, 1995, seventy-eight sampling trips were made aboard commercial lobster vessels. A total of 41,405 lobster was sampled from 15,818 trap hauls. The catch rate of marketable lobster, 0.893 lobster per trap, was 8% lower than the 1994 index, 0.966. The proportion of females ovigerous, 14.1%, was higher than in the previous year (10.7%). The coast-wide fishing mortality estimate, 1.32, declined from the 1994 index of 1.41. Exploitation rate, 0.66, also declined from 0.68 the previous year, while mean carapace length of marketable lobster, 89.2 mm and mean size of egg-bearing females, 86.6 mm, increased by 0.4 mm and 0.3 mm, respectively. The cull rate, 22%, was similar to the 1994 level. Less than 1% of the lobster sampled from traps were dead.

An index of pre-recruit abundance was created using data from our sea sampling database. The catch rate of lobster in the pre-recruit size class provided the basis of the index. The index was calculated from a multiple regression of log transformed catch rates with the following factors: month, year, lobsterman. The back-transformed regression coefficient associated with the factor "year", adjusted for the effects of the other analyzed factors, provided the index of pre-recruit abundance. The relationship between the index and the territorial catch in the following year was modelled using a power function. The resulting equation was used to calculate predicted landings which differed from the actual landings for the years 1981-1995 by 1.1 to 16.6% with a mean difference of 7.3%.

A time series of data from our bottom water temperature monitoring program is presented for seven locations in Buzzards Bay and Cape Cod/Massachusetts Bay.

INTRODUCTION

This is the Massachusetts Division of Marine Fisheries (DMF) fifteenth annual assessment of the status of the American lobster resource in Massachusetts coastal waters. Since the lobster resource supports the most economically important single-species fishery in Massachusetts coastal waters, a long-term coastwide lobster monitoring program yielding biological and catch per unit effort data was devised and initiated in Massachusetts in May, 1981. A sea sampling/survey design was chosen by which both catch per unit effort and biological data could be collected temporally and areally with sufficient precision for stock assessments. The objective was to assess variations in population parameters due to environmental factors, fishing pressure, and regulatory changes.

Data collected during the 1995 coastwide commercial lobster trap sampling program are summarized below. Parameter trends occurring during the 1981-1995 study period are presented.

STUDY AREA

The study area is primarily defined by the Massachusetts territorial sea, except where lobstering activities of cooperating commercial lobstermen exceeded territorial boundaries (Figure 1). Territorial waters total 5,322 sq km (2,055 sq n mi), of which an estimated 60% is considered major lobster habitat. Six sampling regions, Cape Ann, Beverly-Salem, Boston Harbor, Cape Cod Bay, outer Cape Cod, and Buzzards Bay, were chosen for coverage of the major lobstering regions of the state. For convenience, these regions are depicted in Figure 1 as generalized hatch-marked areas wherein lobster gear sampled may be discontinuously distributed.

SAMPLING PROCEDURE

Sampling of coastal waters was accomplished by monitoring catches during the normal lobstering operations of volunteer commercial lobstermen in each designated region. Multiple lobstering operations were observed to reduce bias from varying degrees of lobstering skill and to enhance areal coverage. Pot-sampling trips were day trips, conducted a minimum of once per month per region during the major lobstering season, May-November.

Utilizing portable cassette tape recorders, sea samplers recorded carapace length (to the nearest mm); sex; and condition, including the degree of shell hardness, culls and other shell damage, external gross pathology, mortality, and presence of extruded ova on females (ovigerous). Catch in number of lobster, number of trap hauls, set-over-days, trap and bait type were also recorded. Trap locations were recorded from LORAN and

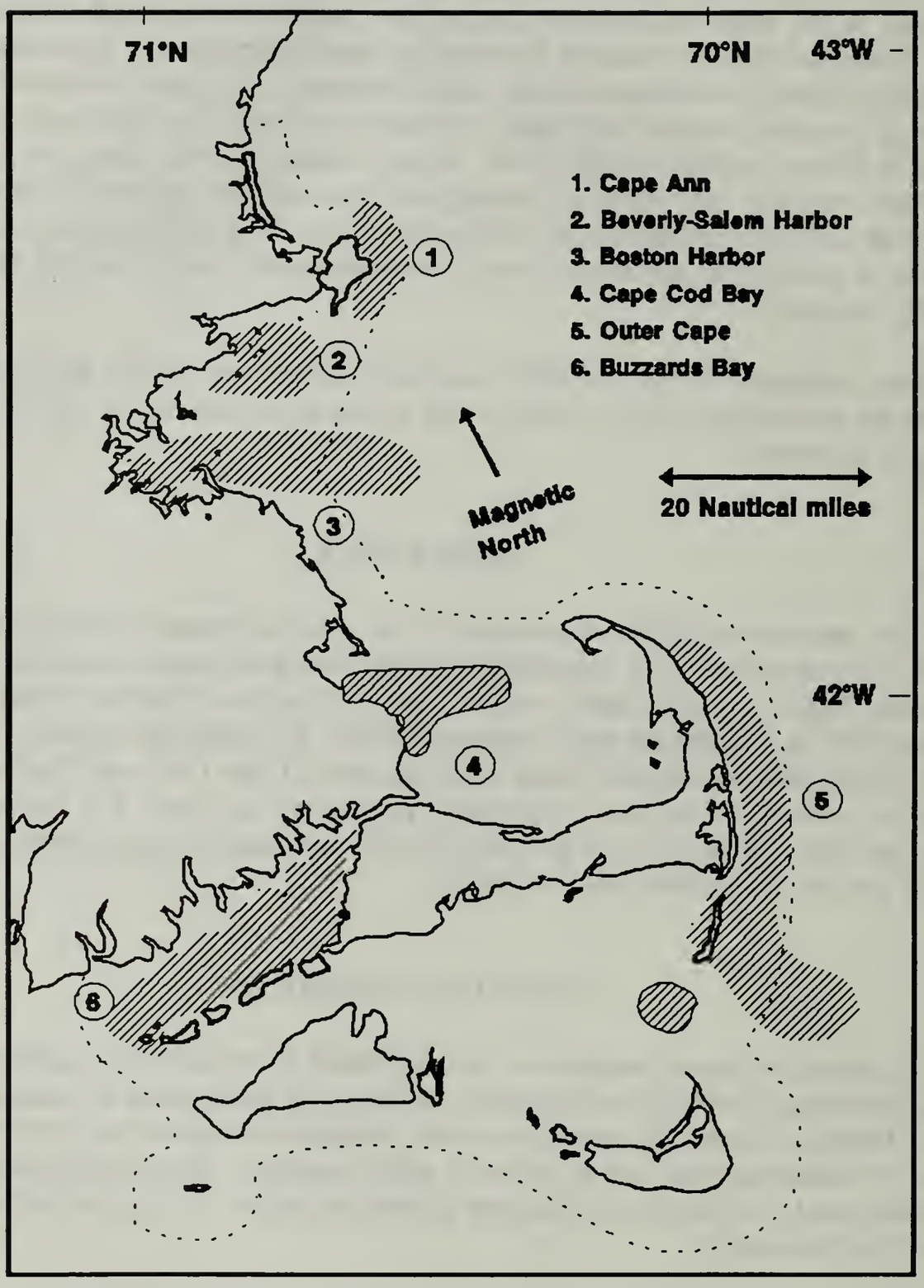

Figure 1. Map of Massachusetts with six sampling regions (hatch-marked) and territorial sea boundary (dotted line) indicated.

plotted on nautical charts. Depth information was then acquired from the charts as a coast-wide standard to avoid variability from tidal fluctuations.

ANALYTICAL PROCEDURES

Data were computer coded and keypunched with a microcomputer data entry program. The data base was subsequently transferred for analysis to the Massachusetts Executive Office of Environmental Affairs' (EOEA) Digital Equipment Corporation VAX-11/780 computer system. A computer auditing process was used to uncover keypunch and recording errors and statistical analyses were performed with SPSS (Nie 1983) statistical sub-programs.

Because parameter means exhibit significant regional and monthly variation, an areal and temporal data weighting scheme was incorporated into analytical software. As a result, each month's data contribute equally to regional parameter means which are weighted by area in square nautical miles to generate coastwide means.

Unless specified otherwise, the terms "legal" or "legal sized" lobster include all lobster in the carapace length category $\geq$ 82.6 mm. The marketable segment of this category, which excludes ovigerous females, is analyzed separately and referred to as "marketable lobster". The sublegal length category includes all lobster < 82.6 mm.

The catch rates of marketable lobster are expressed as CTH'_3. This is catch per trap haul standardized to 3 set-over-days (Estrella and McKiernan 1989).

Estimates of total instantaneous mortality (Z) and total annual mortality ($A=1-e^{-Z}$) were computed by two methods which produce extremes in the possible range of estimates. The method of Gulland (1969) requires computation of the regression line slope of natural log transformed numbers at estimated age (15% molt groups, 14% for Buzzards Bay, were derived from tagging data). Beverton and Holt's (1956) process employs von Bertalanffy Growth Equation parameters (from Fair 1977) and mean and minimum length of exploitable sizes.

Estimates of fishing mortality (F) were calculated with cohort analysis (Pope 1972, Jones 1974). Rates of exploitation were calculated with the equation $u=FA/Z$, where F= fishing mortality, A= total annual mortality, and Z= total instantaneous mortality.

Lobster landings data were derived from lobstermen's catch reports which are compiled annually by the DMF Commercial Fisheries Statistics Project.

Since current management strategy stresses uniform coastwide regulations, all data are grouped for a coastwide analysis. However, the uniqueness of the Massachusetts coastline, its role as a temperature barrier which profoundly affects many marine species

(Colton 1964), and the influence of offshore lobster stocks on the inshore resource mandate a regional data treatment as well.

RESULTS

Commercial Lobster Sampling

During the period of May through November, 1995, seventy-eight sampling trips were made aboard commercial lobster vessels in Massachusetts coastal waters. A total of 41,405 lobster was sampled from 15,818 trap hauls.

The 1995 coastwide mean catch per unit effort index (CTH'_3), 0.893 marketable lobster per trap, was 8% lower than the 1994 index, 0.966 (Appendix Table 1). Total Massachusetts commercial landings, 15,949,363 lbs, decreased by 1.4% from 1994. Landings from territorial waters, 10,086,601 lbs, decreased by 3.9%. Landings and catch rate trends are depicted in Figure 2. The catch rates of sublegal lobster increased slightly between 1994 and 1995 (Appendix Tables 2 and 3).

Of all females sampled during 1995, 14.1% were ovigerous compared to 10.7% in 1994 (Appendix Table 4). Trends in CPUE of ovigerous females also improved and are depicted in Figure 3 (Appendix Tables 4-6).

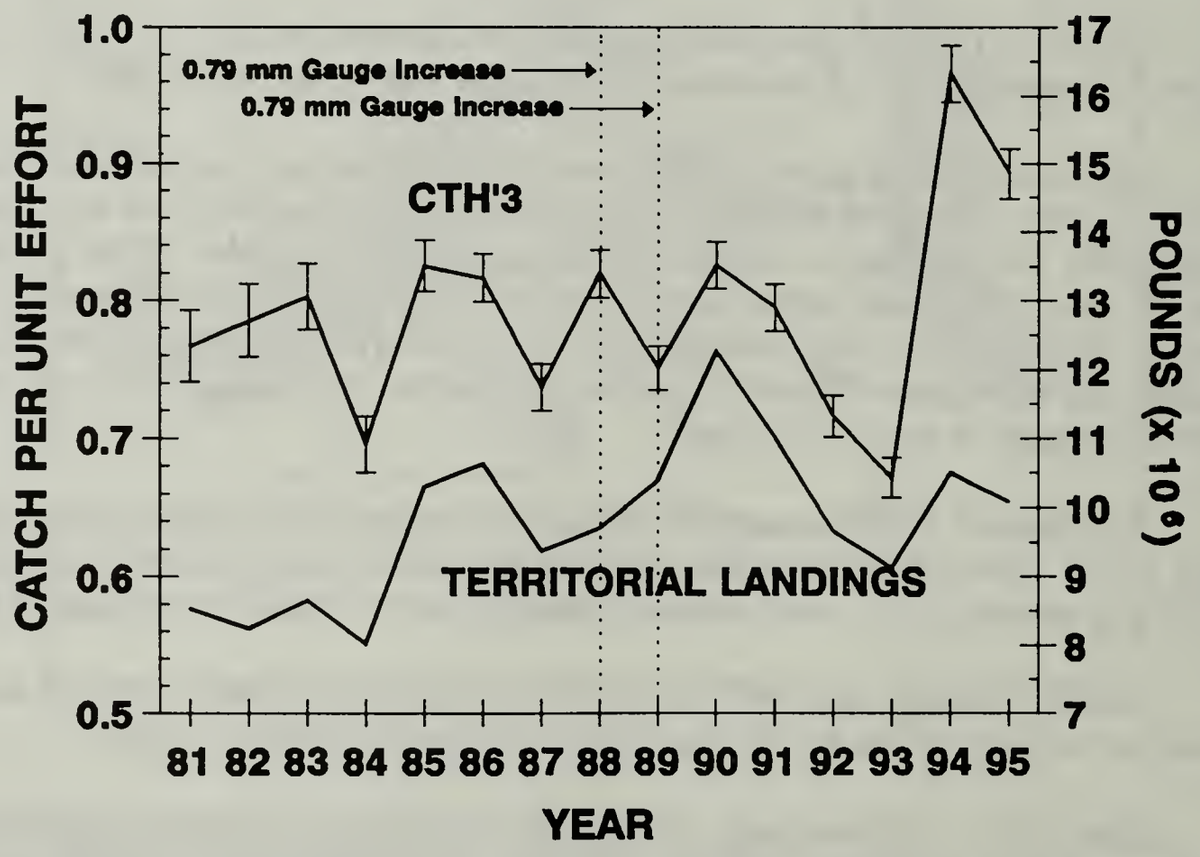

Figure 2. Catch per unit effort of marketable American lobster from commercial trap sampling and Massachusetts lobster landings from territorial waters, 1981-1995.

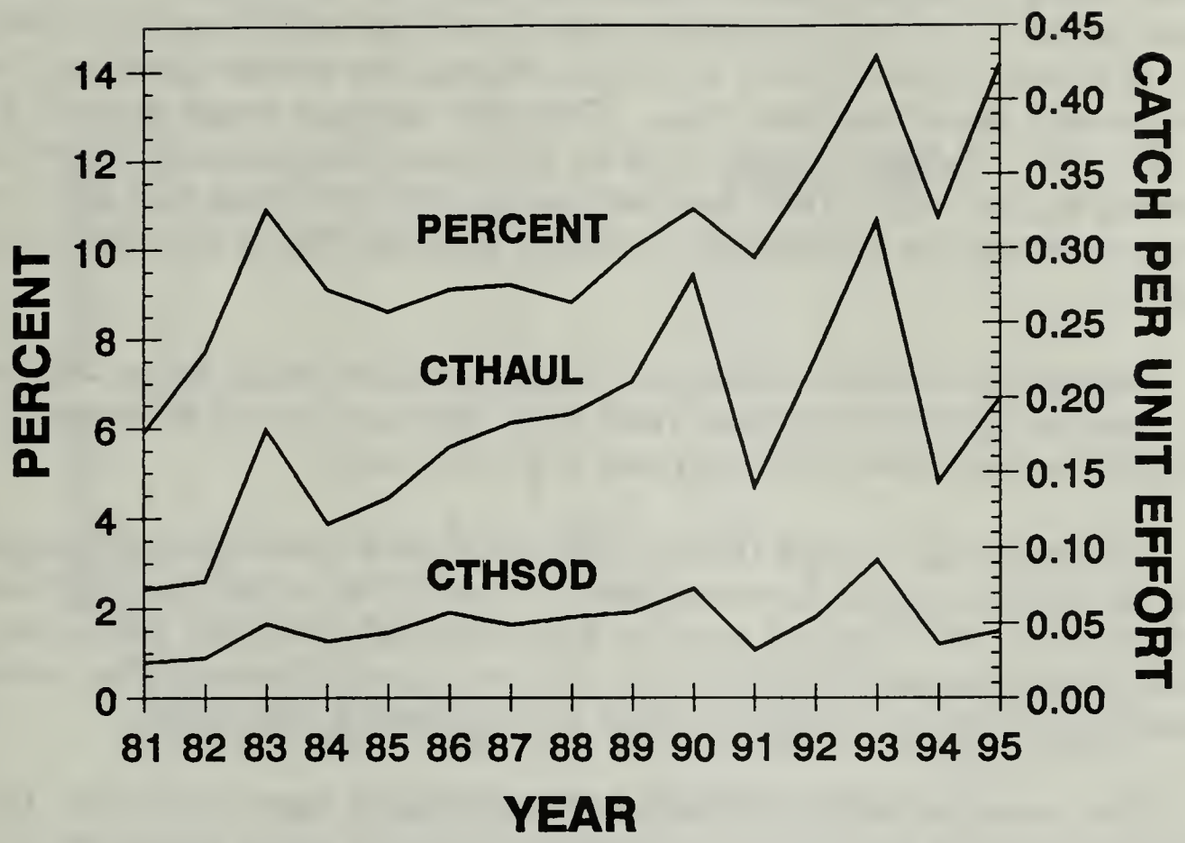

Figure 3. Relative abundance of ovigerous female American lobster in percent total females and catch per effort, Massachusetts coastal waters, 1981-1995.

Approximately 92% of the legal catch in our inshore regions (Cape Ann south through Cape Cod Bay and Buzzards Bay) was comprised of new recruits (83 mm-94 mm CL), i.e., lobster which recruited to the legal size range during their most recent molt (Appendix Table 7). This index of the effect of fishing pressure on the size frequency was lower than 1994. The index fluctuated from 60% in 1994 to 55% in 1995 for the primarily offshore migrant lobster sampled east of Cape Cod. Estimates of total mortality (Z) for inshore Gulf of Maine regions (Z = 1.62-3.10, A = 80%-95%) and Buzzards Bay (Z = 2.44-3.34, A = 91%-96%) depict a heavily exploited resource while those for the outer Cape Cod region (Z = 0.72-0.74, A = 51%-52%) indicate that a lower level of fishing pressure was exerted on this lobster group (Appendix Tables 8a and 8b).

Estimates of instantaneous fishing mortality (F), the proportion of all deaths which are attributed to fishing, ranged from 0.62 off outer Cape Cod to 2.05 in Buzzards Bay (Appendix Table 9). Exploitation rates (u), i.e. the fraction of the population that is removed by fishing, were similar to 1994 data (Appendix Table 10).

The relationship between fishing mortality, rate of exploitation, and mean lobster size is depicted in Figure 4. Carapace length exhibited a downward trend as fishing

mortality and exploitation rates increased through 1987. Thereafter increases in mean carapace length of 0.7 mm occurred in 1988 (mean size = 88.2 mm) and 1989 (mean size = 88.9 mm, Appendix Table 11) which reflected the similar numerical change in the minimum legal size during those years. Thereafter carapace length fluctuated downward until 1994-1995. Fishing mortality rates for all regions combined edged upward to a time-series high of 1.48 in 1993, then declined in 1994-1995 along with exploitation rates. The relative change in size frequency between 1994 and 1995 is depicted by the overlay in Figure 5.

Sublegal sized lobster averaged 77.8 mm carapace length during 1995 compared to 77.5 mm during 1994 (Appendix Table 12). The mean size of all ovigerous females was similar between 1994 (86.3 mm) and 1995 (86.6 mm).

The percentage of culls (lobster with one or both claws missing or regenerating) among all lobster sampled fluctuated upward from 21.9% in 1994 to 22.0% in 1995 (Appendix Table 14). The cull rates for legal and marketable size groups were similar between years (Appendix Tables 15-17). The cull rate for Buzzards Bay increased substantially and nearly doubled for legal and marketable size groups.

The coastwide incidence of lobster found dead in traps was 0.21%. This was similar to that of the previous year (Appendix Table 18) and is acceptably low.

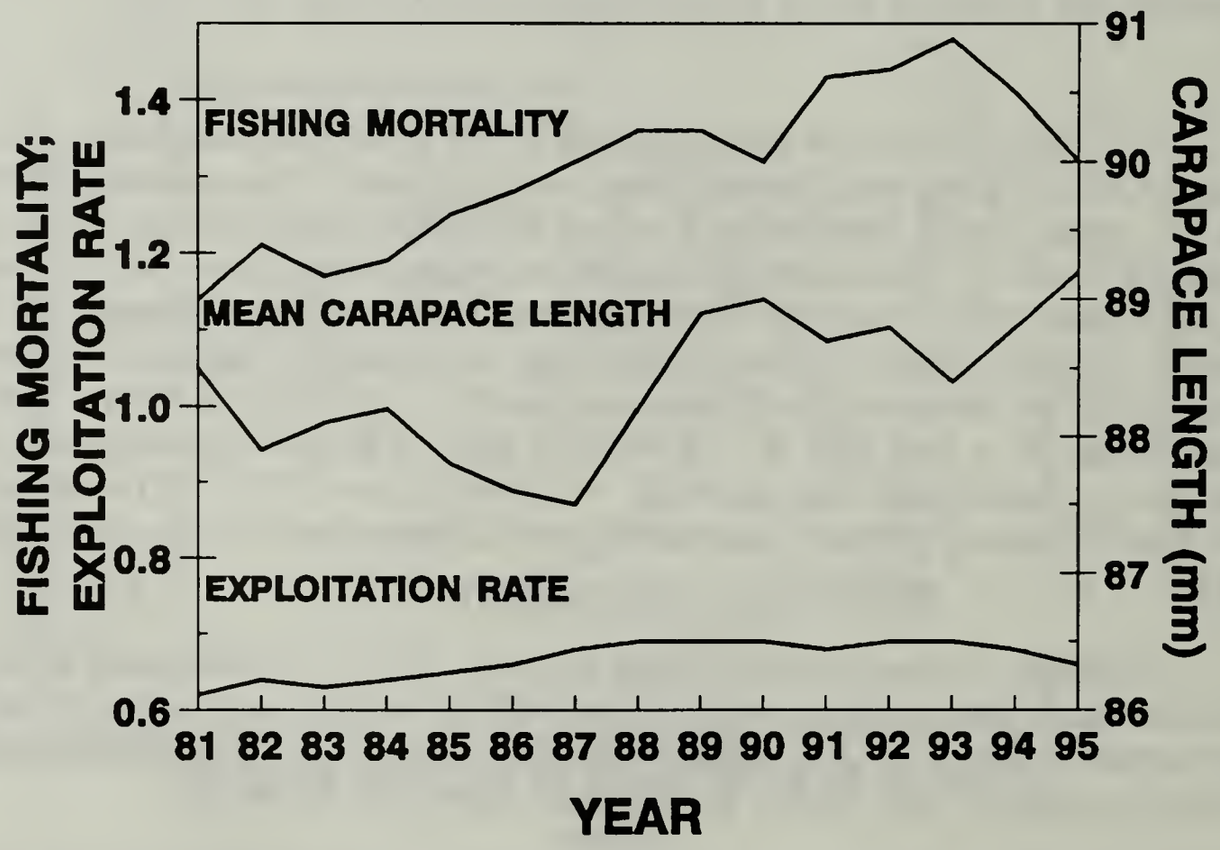

Figure 4. Relationship between exploitation rate, fishing mortality, and mean carapace length of marketable American lobster, Massachusetts coastal waters, 1981-1995.

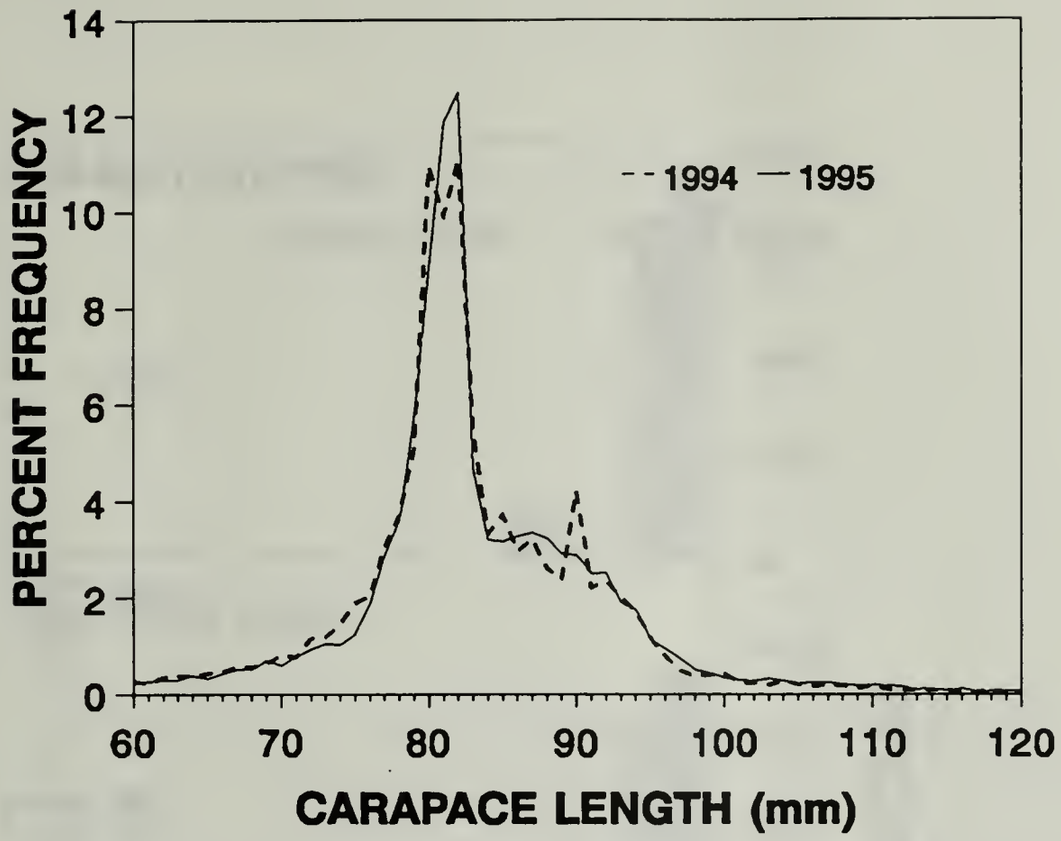

Figure 5. Length frequencies of trap-caught American lobster, Massachusetts coastal waters, 1994-1995.

DISCUSSION

Commercial fishing activities have impacted the American lobster length frequency composition in Massachusetts coastal waters. The size range is truncated and large lobster are reduced in number, particularly in inshore waters where the greatest fishing effort is expended. A previously published comparison of the size composition of several Massachusetts regions over a thirty year period (1957-1986; Figure 6) demonstrated that older, larger lobster comprised a greater proportion of the catch in 1957 (Estrella and McKiernan 1989). Numerous historical records dating back as far as the 1600's support the argument that large lobster were more abundant inshore prior to the intensification of commercial fishing practices.

The impact of intense fishing affects the size composition of egg-bearing females and potential egg-production as well. This raises concern about the need to mediate excessive fishing pressure on this resource. A comparison of size at fecundity curves over a 100-year time period from southern Massachusetts waters (Estrella and Cadrin 1995) shows several important points (Figure 7). First, the size range of lobster available in inshore waters in the late 1800's far exceeded contemporary profiles. Also egg counts at size and the smallest egg-bearing female observed were virtually the same. Barring

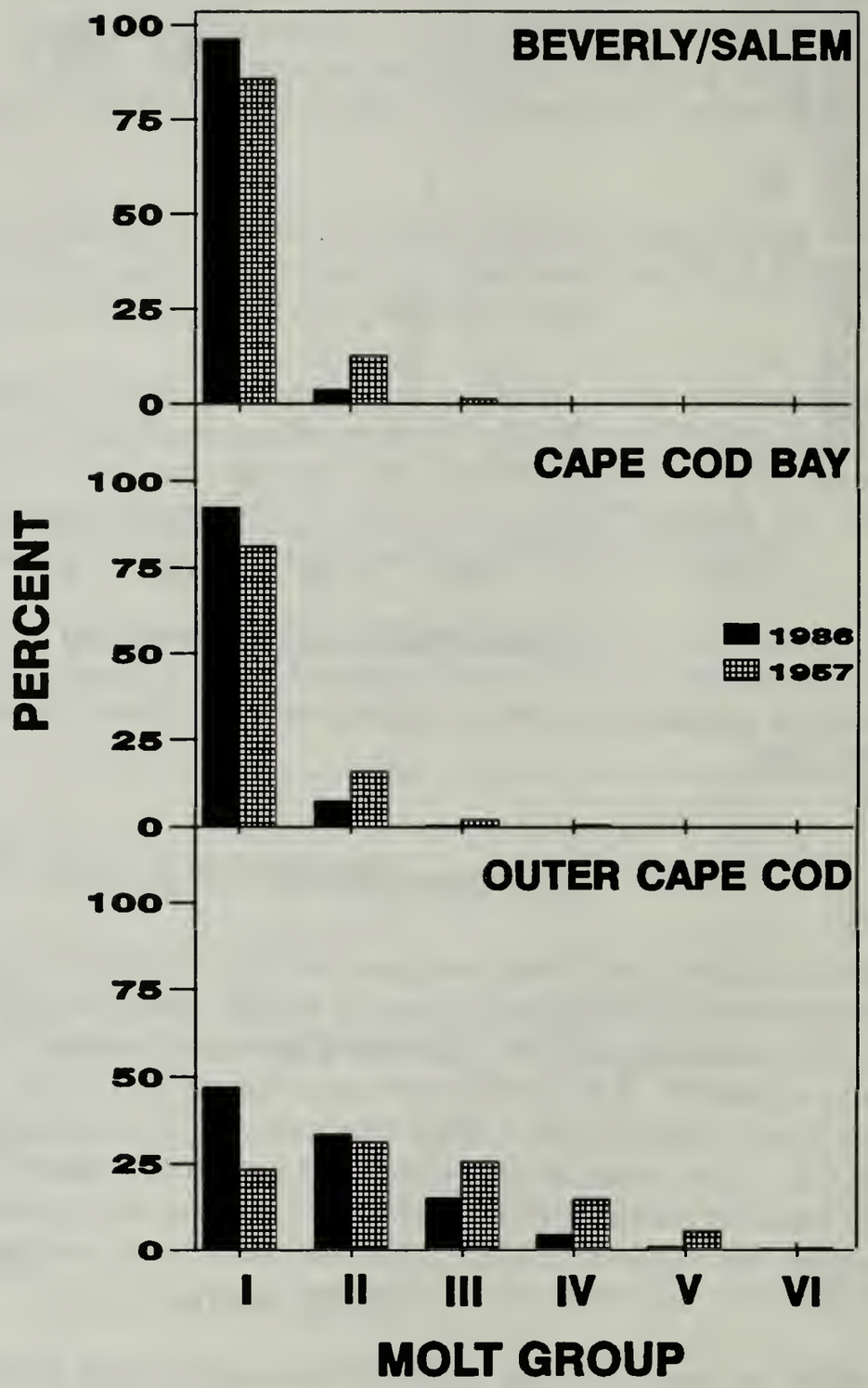

Figure 6. Comparison of 1957 and 1986 marketable American lobster size-frequency data from three coastal Massachusetts regions by 15% molt groups: I 81-93 mm, II 94-108 mm, III 109-125 mm, IV 126-145 mm, V 146-168 mm, VI 169-194 mm.

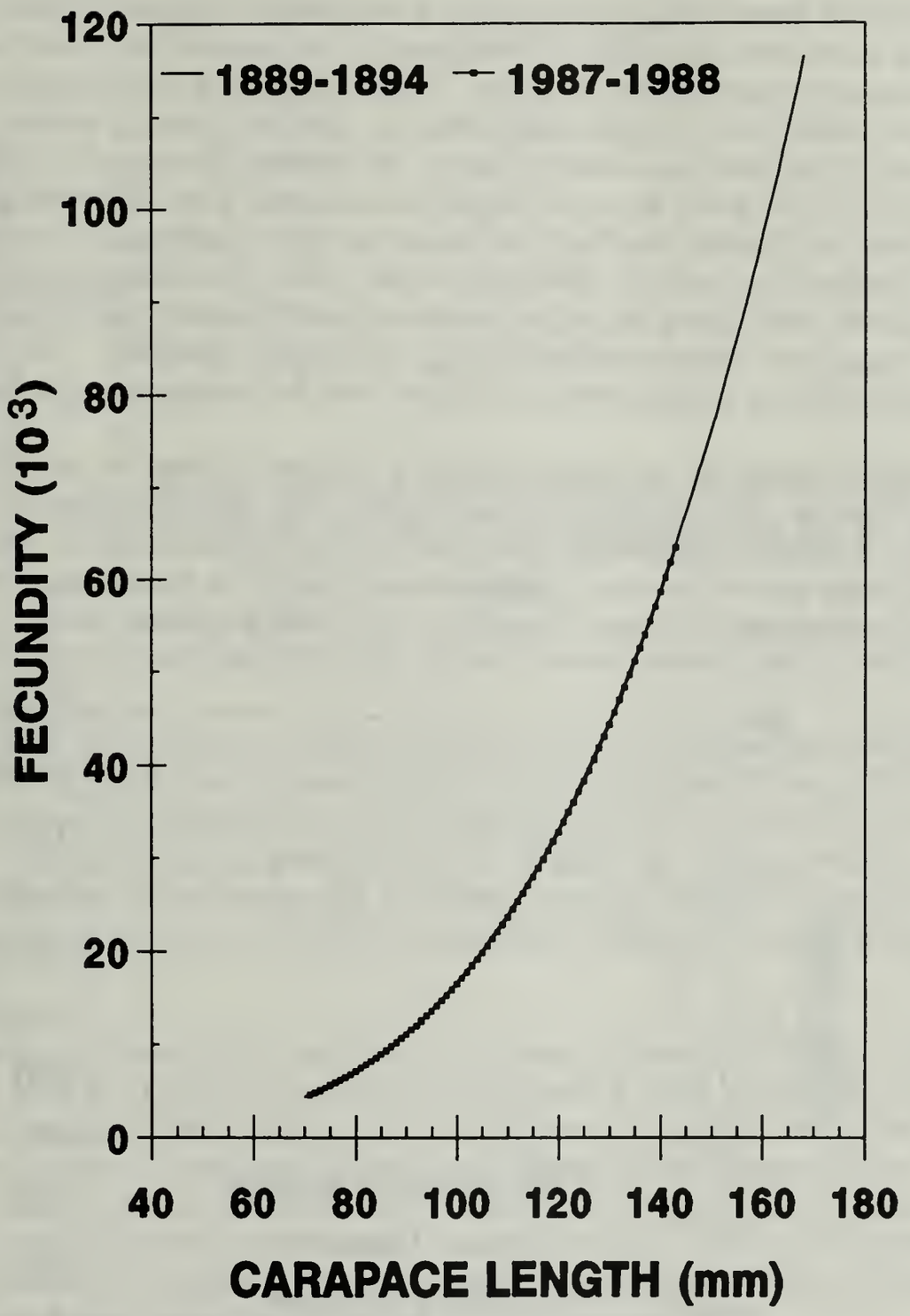

Figure 7. Size-fecundity relationships studies conducted in southern Massachusetts waters, 1889-1894 and 1987-1988.

changes in growth rate over the past 100 years, this species has not compensated for the intense fishing effort levied upon it, unlike some finfish which may respond to population reduction by increasing fecundity.

Available data on egg production and recruitment support a rather steep stock-recruitment curve for this species. Consequently, the number of pounds landed is not a good indication of status of the resource. High exploitation depresses the average size of lobsters and abundance of egg-bearing females. This can cause a sudden, adverse effect on recruitment and lead to a stock collapse. In addition to research conducted in U.S. waters, attention has been drawn to supportive evidence from Newfoundland lobster work and also the Bristol Bay Red Crab resource which collapsed within two years after 15 years of increasing landings (Bannister et al. 1996). This information illustrates the necessity for an overfishing definition based on female lobster egg production to help managers gauge the minimum allowable egg production threshold. This threshold should not be interpreted as a target but as a danger level for management action.

Possible causes for increased American lobster landings in recent years include a number of factors. Fishing effort has intensified: the number of licenses issued and traps fished increased significantly since the 1970's (Figures 8 and 9). Declines since the late 1980's were due to attrition from implementation of a moratorium in 1988-1992 and subsequent retirement of licenses mandated by a 1993 regulatory revision.

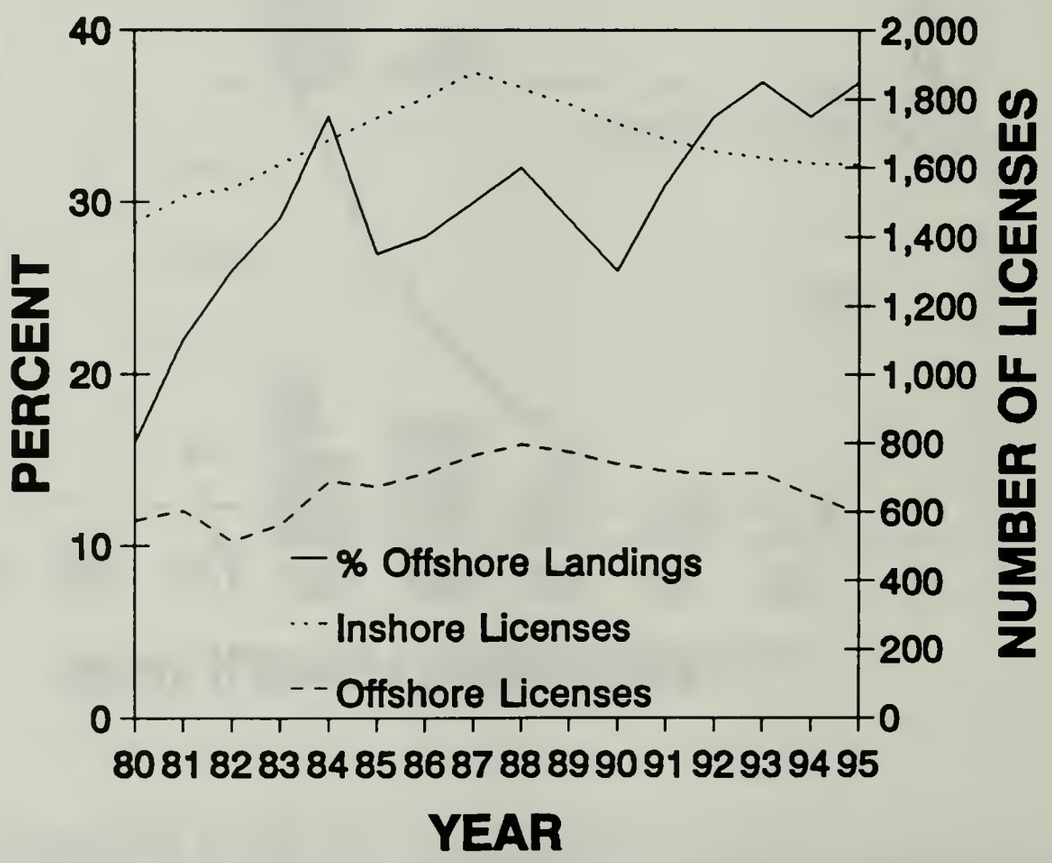

Figure 8. Trend in Massachusetts commercial lobster landings from offshore waters and inshore and offshore licenses issued.

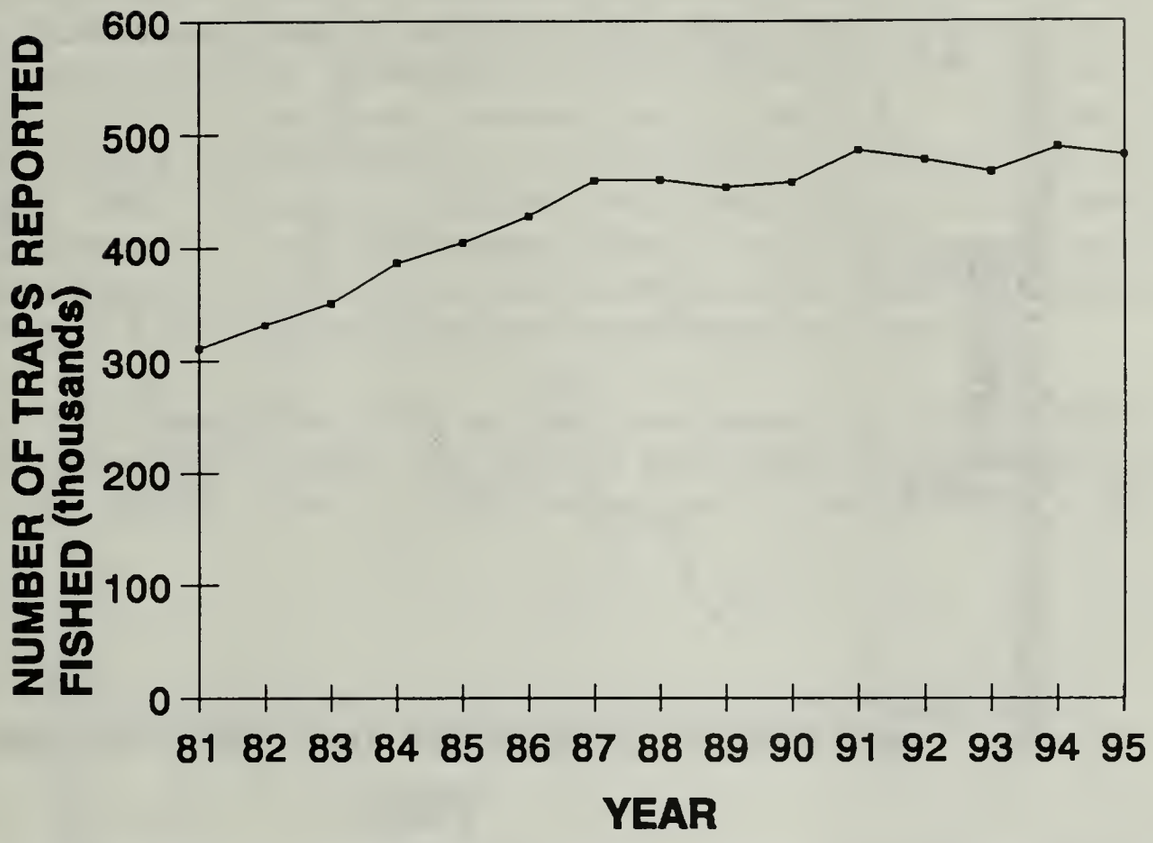

Figure 9. Total traps reported fished by Massachusetts commercial lobsterman, 1981-1995.

Historically, only a narrow band of coastal waters off Massachusetts (the area shoreward of the 120 ft contour) concentrated the bulk of lobster fishing effort. Following the saturation of this area by fishing gear, expansion beyond this contour to relatively less exploited habitat naturally occurred (Figure 8). Also, increased competition and effort for lobster in fall and winter months (Figure 10) has contributed to increased landings, but has resulted in eliminating a formerly substantial spring fishery.

Generally, improved fishing efficiency may have enhanced landings. The use of electronic aids such as LORAN C and color depth finders allow consistent locating of prime grounds; hydraulic pot haulers allow more gear to be hauled in a given time period; and an increase in the use of wire traps (Figure 11) which are known to produce greater catch rates compared to wood traps (Acheson 1980) has occurred. In addition, the escape vent requirement, which became law on January 1, 1977 for commercial gear, reduces trap saturation, increases CPUE of legals, mitigates interaction and mortality within traps, and reduces handling (Estrella and McKiernan 1989).

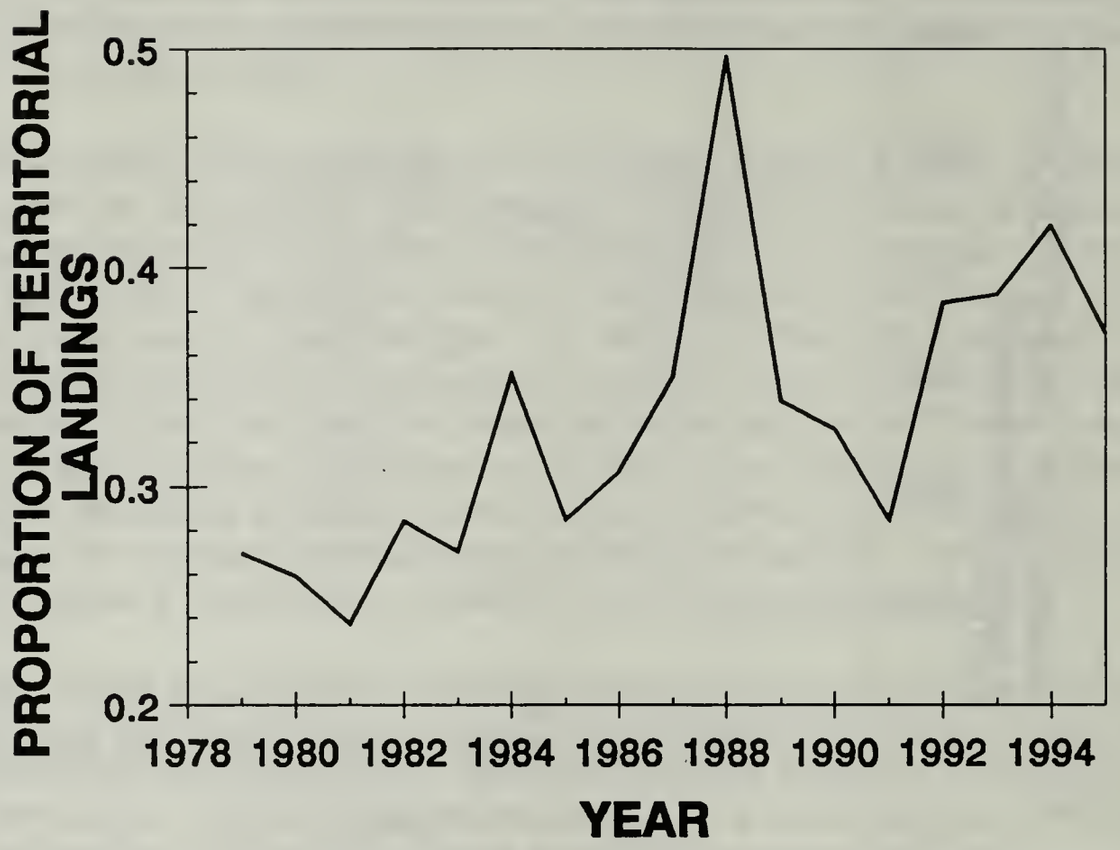

Figure 10. Proportion of Massachusetts territorial lobster landings taken during October-February period.

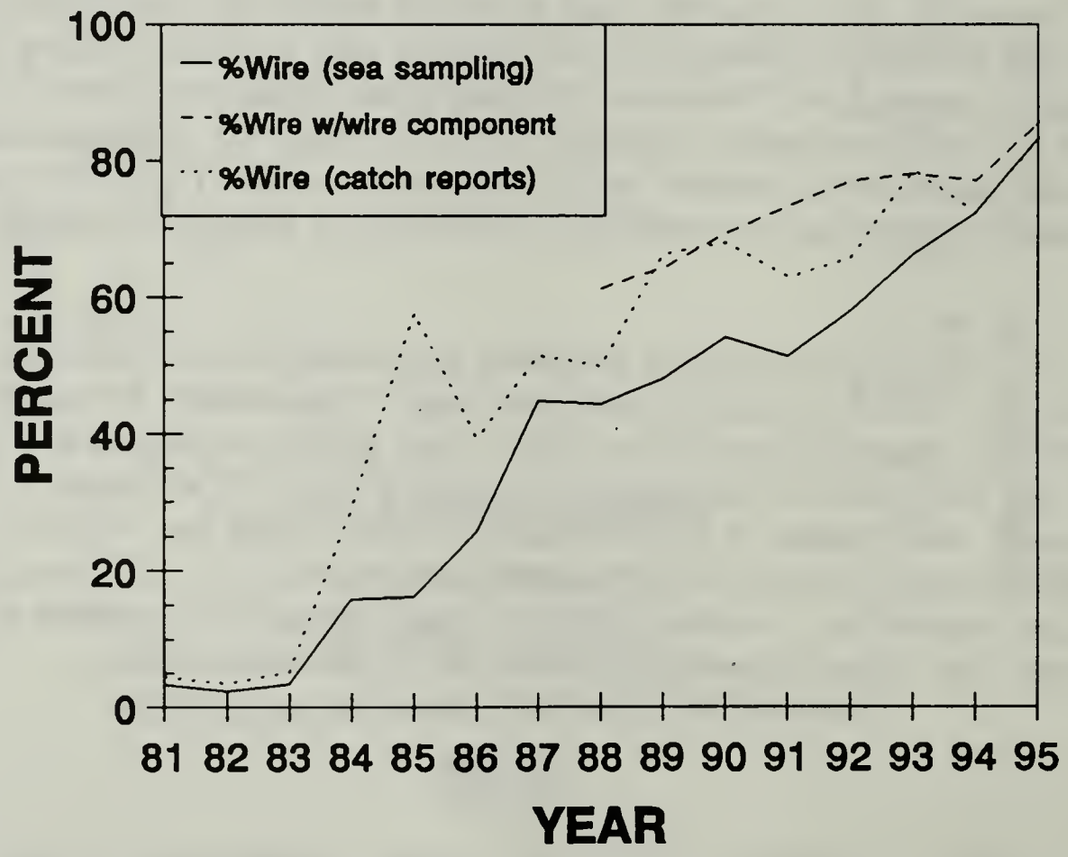

Figure 11. Trend in use of wire traps by Massachusetts commercial lobstermen.

Speculation about enhanced abundance due to favorable environmental conditions, e.g. a warming trend in the 1970's-1980's which could enhance larval survival and increase molt probability, are supported by results from the latest coastwide stock assessment (SARC 22). Trawl survey catches of pre-recruits show an increasing trend. Water temperature has increased since the 1960's (Figure 12). Temperatures in the late 1940's to early 1950's were nearly as high as in recent years (Figure 12), yet landings were significantly lower. It would be inappropriate to assume that temperature is the primary factor affecting recruitment, but it is important. Nevertheless, it is unclear what additional factors may have positively affected recruitment in recent years.

Some stabilization in the profile of the lobster resource in Massachusetts coastal waters occurred in 1994 and 1995. Mortality and exploitation rates declined as carapace length increased slightly. However, fishing pressure on this resource remains high.

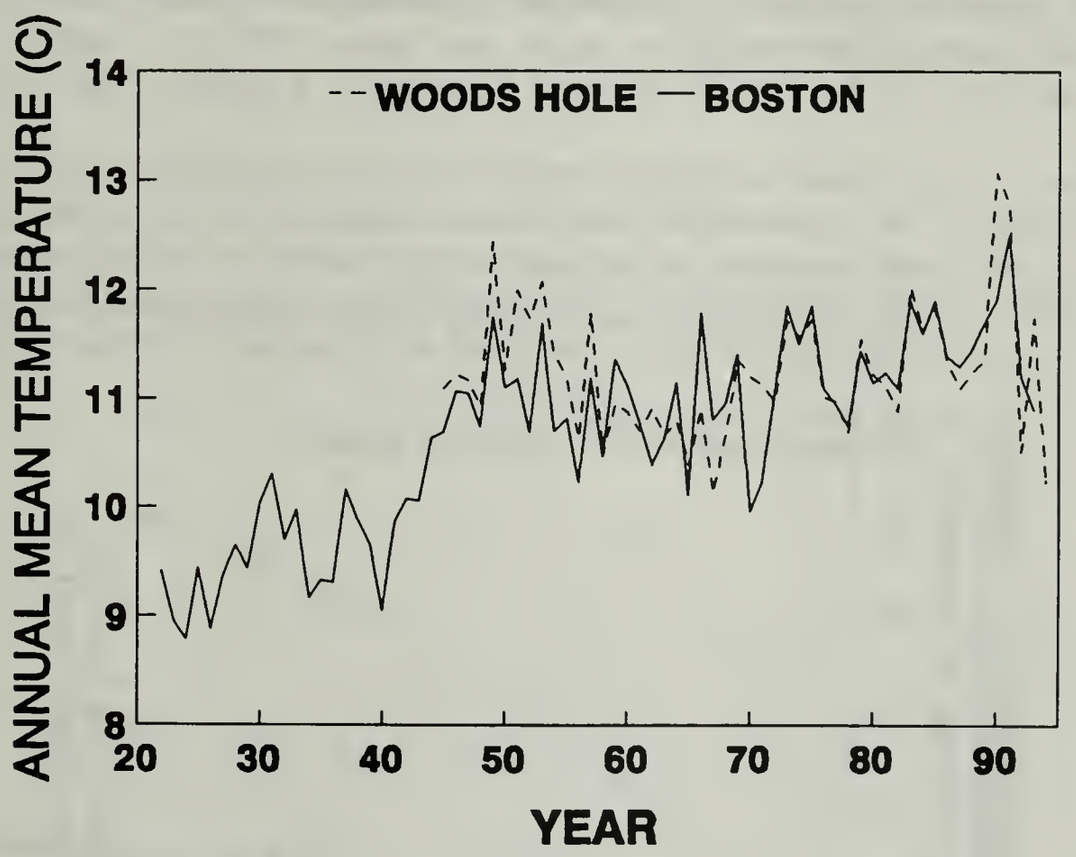

Figure 12. Annual mean sea surface temperature from NOAA/NOS Woods Hole and Boston Harbor stations.

INDEX OF PRE-RECRUIT ABUNDANCE

Using data from our sea sampling program, we created an index of abundance for pre-recruit lobster. The catch rate (number caught per trap haul) of lobster in the pre-recruit size class (68-80 mm carapace length for the years 1981-1987; 69-81 mm for 1988; and 70-82 mm for 1989 and later) provided the basis of the index. The index was calculated from a multiple regression of logarithmically transformed catch rates with the following factors: month, year, lobsterman. Other factors including soak time, bait, and trap type were incorporated in the preliminary regressions but failed to improve the fit and so were excluded from the model. The back-transformed regression coefficients associated with the factor "year", adjusted for the effects of the other analyzed factors, provide the index of pre-recruit abundance. This approach using regression/ANOVA modelling in the standardization of catch rates has been used successfully to create indices of juvenile abundance in the Western Australia rock lobster (*Panulirus cygnus*) fishery (Caputi and Brown, 1986).

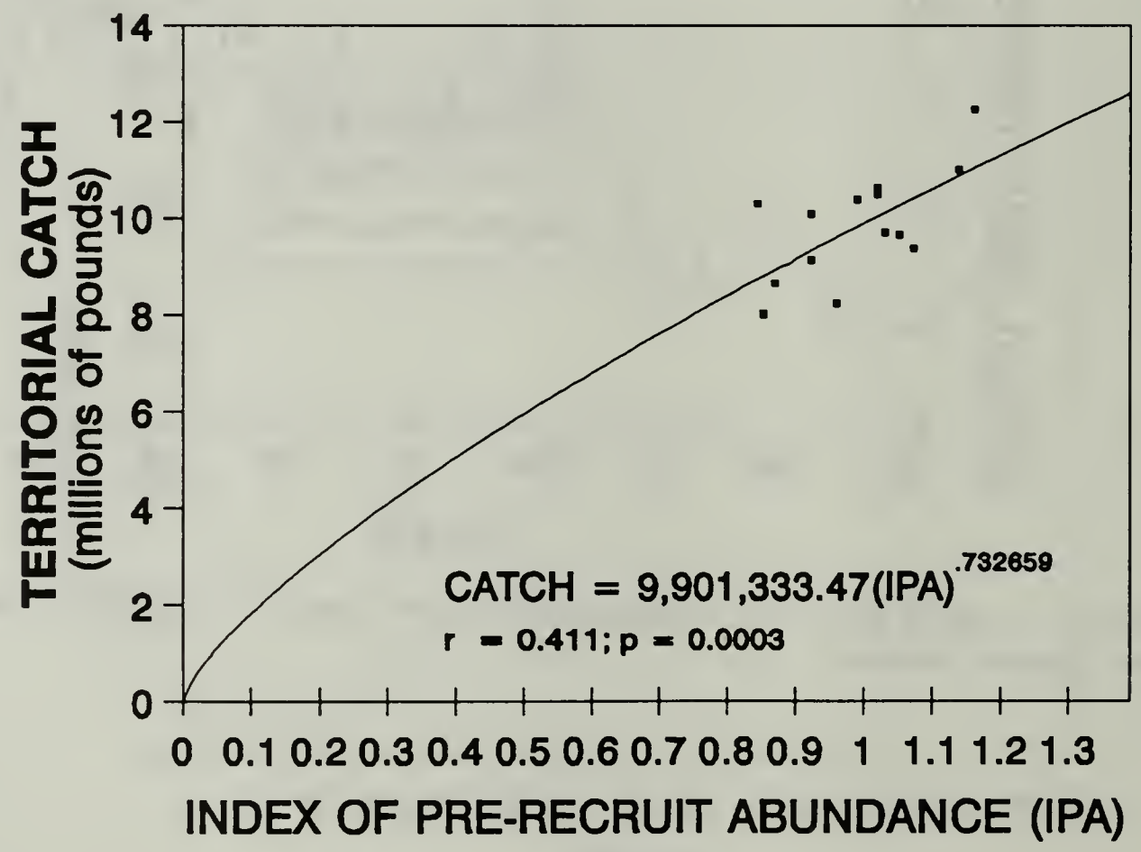

Figure 13. Relationship between the index of pre-recruit abundance and Massachusetts territorial catch one year later.

The relationship between the index of pre-recruit abundance (IPA) and the territorial catch in the following year (Figure 13) was modelled using a power function resulting in the following equation:

$$\mathbf{Catch}_{t+1} = 9{,}801{,}333.47(\mathbf{IPA}_t)^{0.732659}$$

$$r^2 = 0.411; \quad p = 0.0003$$

where $\mathbf{Catch}_{t+1}$ = territorial catch in year t+1

$\mathbf{IPA}_t$ = index of pre-recruit abundance in year t

This equation was used to predict territorial landings. The relationship between predicted territorial landings and actual territorial landings is shown in Figure 14. The predicted values differed from the actual values by 1.1 to 16.6% with a mean difference of 7.3%.

The relatively tight fit between predicted and actual landings ($r = 0.66$, $p = 0.0002$) indicates the model provides modest predictive power for territorial landings. The fit improves in the years after 1987, which may relate to improved catch reporting. The model predicts a slight decrease in territorial landings for 1996 to 9,757,318 lbs.

This model is simplistic in that it does not consider all the sources of variation such as annual temperature fluctuations and regional differences. An improvement in fit could probably be gained by conducting the analyses on a regional basis but a predictive index with statewide application is more desirable. Future efforts at fine tuning the index will include adding a temperature factor into the multiple regression.

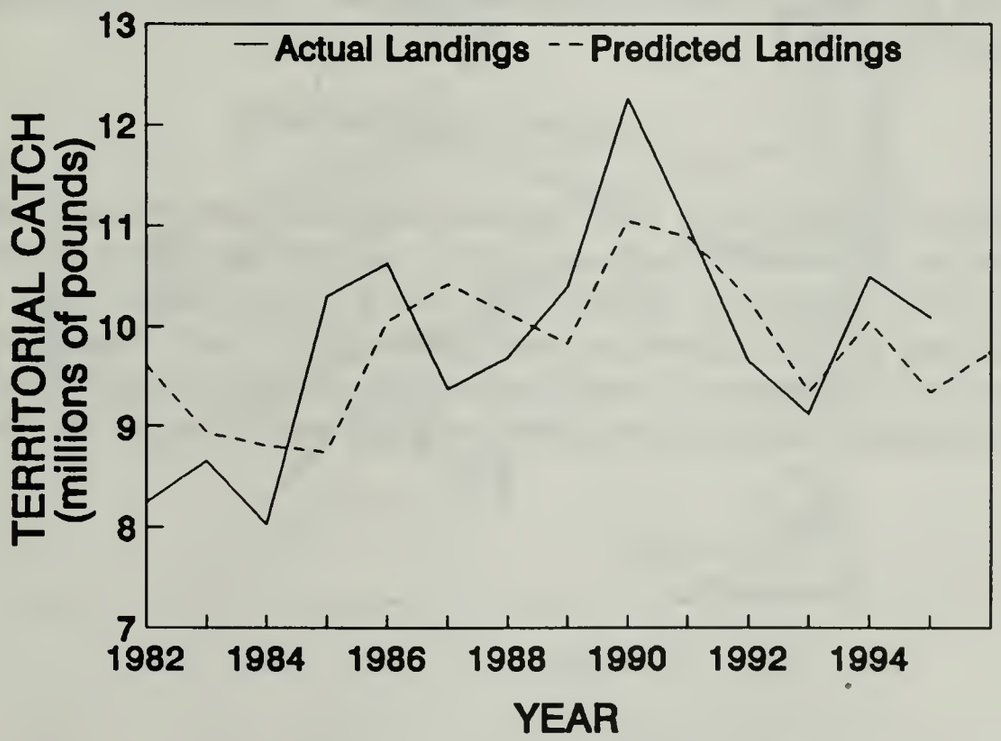

Figure 14. Relationship between predicted territorial landings based on the pre-recruit abundance index and actual territorial landings.

WATER TEMPERATURE TIME SERIES

In 1985, a coastal bottom water temperature monitoring project was initiated. Temperature monitors (RYAN Tempmentor) have been deployed for various lengths of time at several sites in Cape Cod Bay, outside Boston Harbor, and Buzzards Bay (Figure 15). Some of these sites are located on ship wrecks.

The longest time series of bottom temperatures is from Cleveland Light in Buzzards Bay. The last monitor to be deployed was at Rocky Point, off Plymouth. The Rocky Point, Manomet Point, *Endicott*, and *Mars* sites represent the 0-30 ft., 30-60 ft., 61-90 ft., and 91-120 ft. depth strata, respectively, in Cape Cod Bay. The *Romance* (off Boston Harbor), and Buzzards Bay-South sites are located at 70-80 ft. and provide data from the north-south extremes in our series. The Cleveland Light monitor is located in 30 feet of water.

Monitors are retrieved and replaced annually by divers. Although the time series contained data from seven monitors at one point, we currently collect data from only six sites because the monitor at the *Endicott* site was lost and has not been replaced. Figures 16 and 17 present the bottom water temperature at sites in Buzzards Bay and Cape Cod Bay/Massachusetts Bay, respectively. Figure 18 provides a comparison between the annual mean bottom temperature at Cleveland Light, Manomet, *Mars*, and *Romance* and the annual mean surface temperature at Boston and Woods Hole provided by NOAA/NOS.

ACKNOWLEDGEMENTS

We are indebted to the many commercial lobstermen whose cooperative spirit and concern for the American lobster resource sustain our lobster monitoring program. Gratitude is also extended to Jeremy King, Karen Greene, Brad Chase, Doug Potts, and Mike Armstrong for data collection, Ann Spires and Kristen Kobialka for data entry, and James Fair who administered the project and reviewed the manuscript. We also thank Thomas Hoopes for his data entry software design and assistance in data quality control.

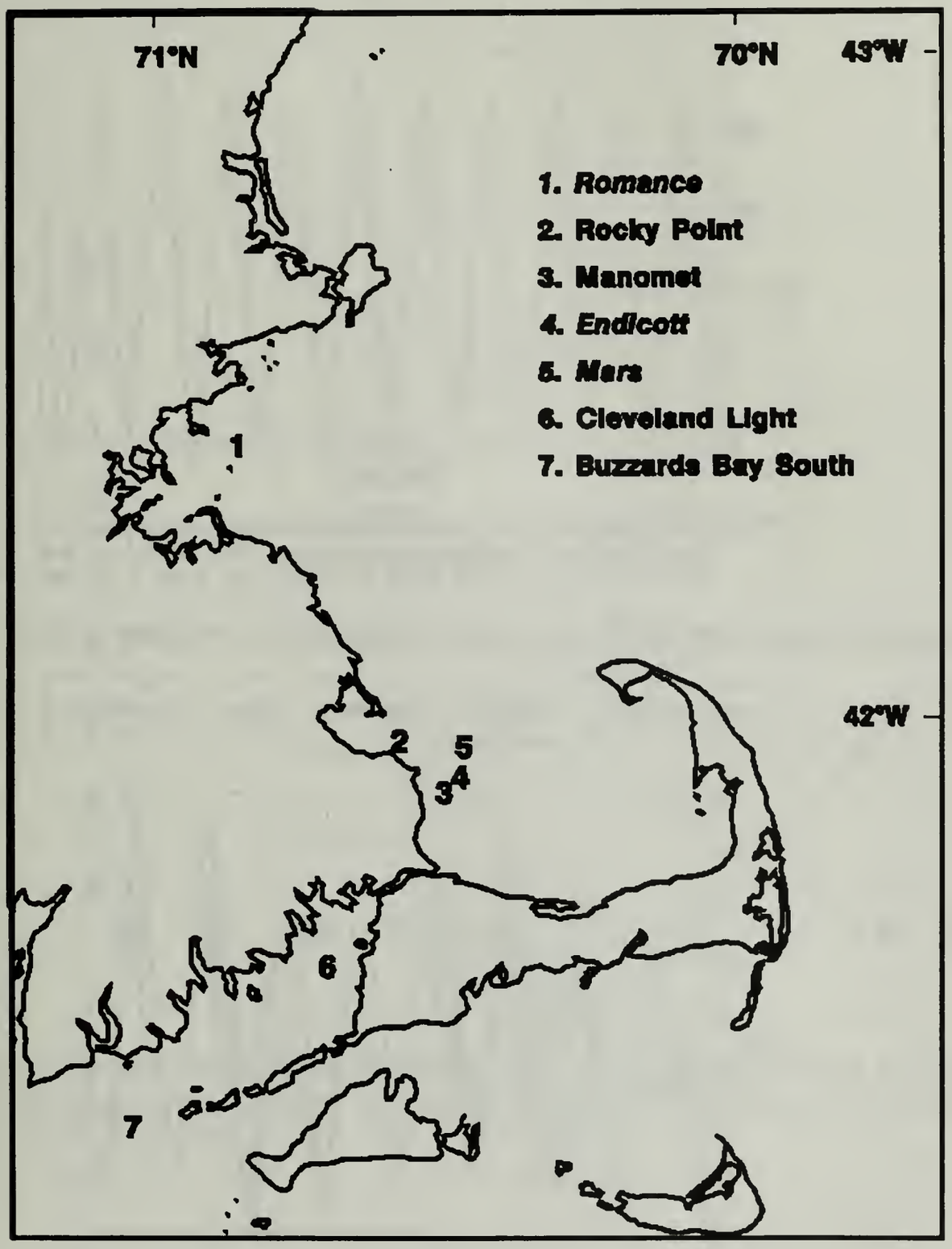

Figure 15. Map of Massachusetts with approximate locations of seven bottom temperature monitors indicated.

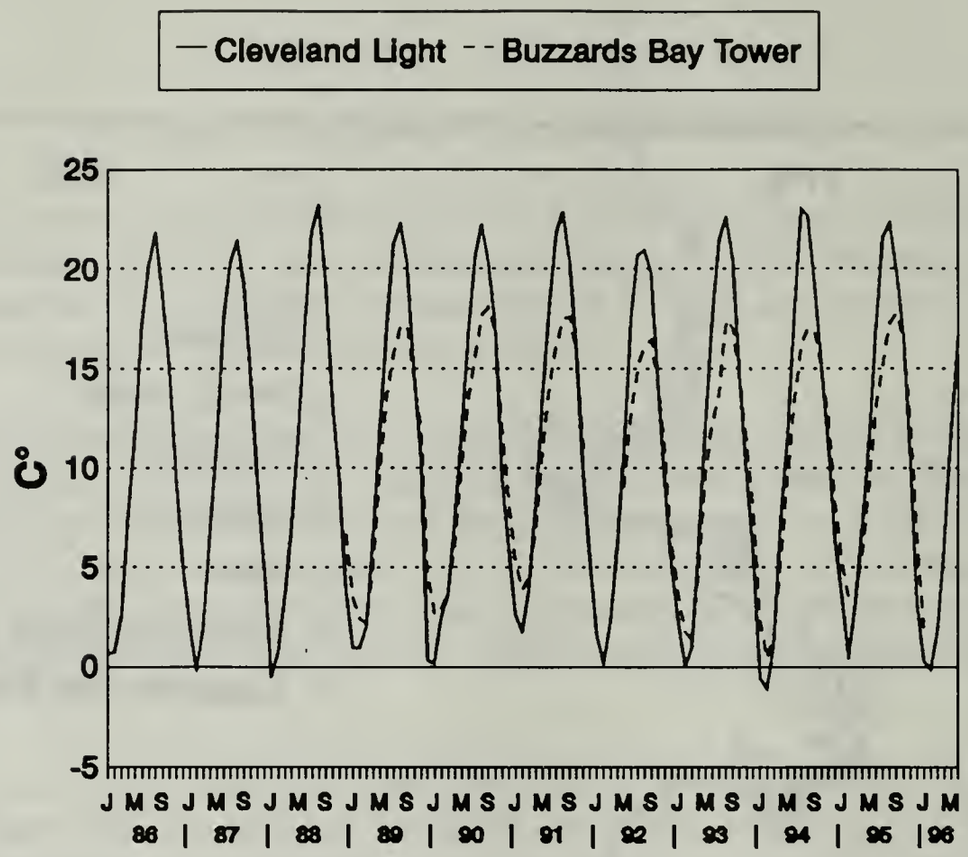

Figure 16. Mean monthly bottom water temperatures at two sites in Buzzards Bay.

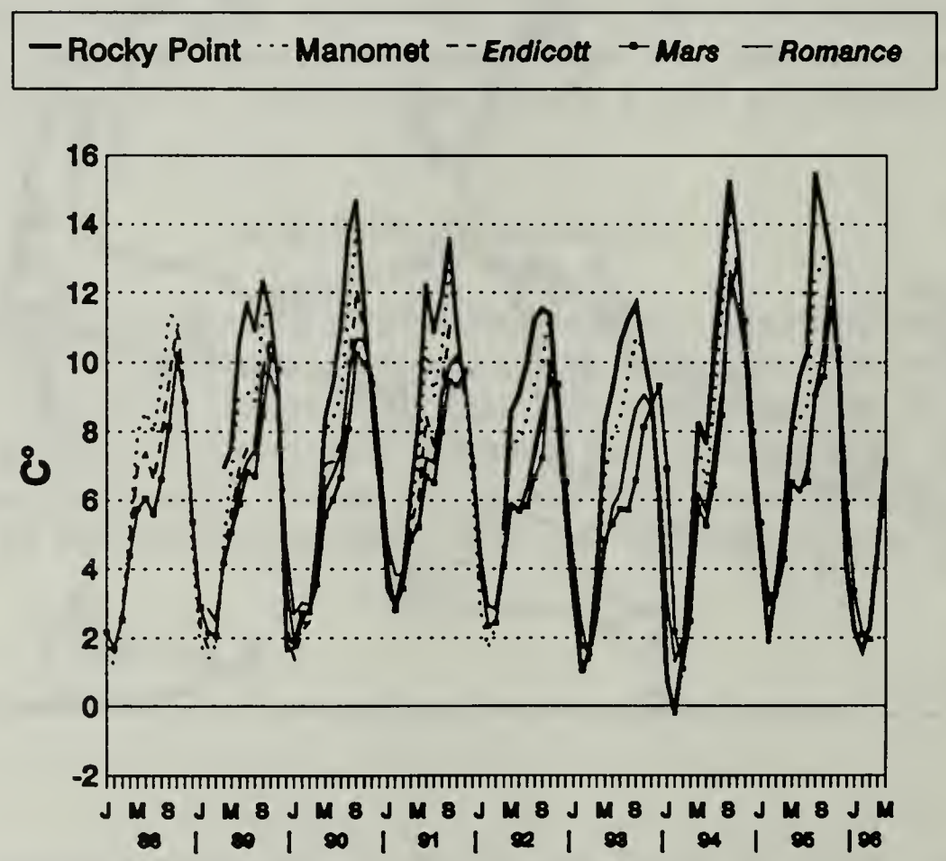

Figure 17. Mean monthly bottom water temperature at five sites in the Gulf of Maine.

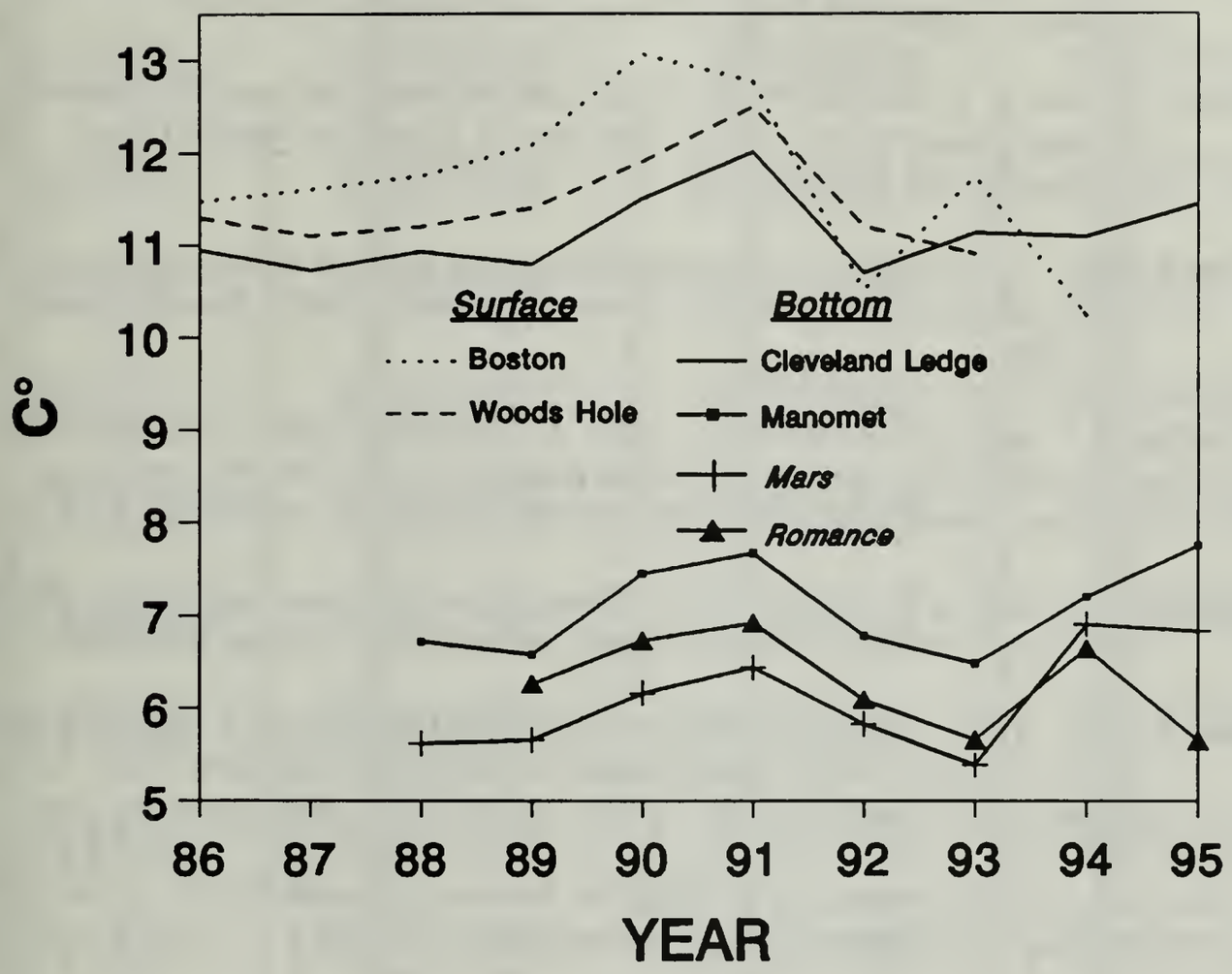

Figure 18. Mean annual bottom temperatures at four sites monitored by the Coastal Lobster Project and mean annual surface temperature at two sites monitored by NOAA/NOS, 1986-1995.

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APPENDIX

Table 1. CTH'3, by state and region, for all marketable lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1995.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
State	0.767	0.785	0.803	0.696	0.825	0.816	0.737	0.730	0.751	0.826	0.795	0.716	0.671	0.966	0.893
Cape Ann	0.732	0.808	0.624	0.663	0.634	0.699	0.669	0.496	0.721	0.904	0.868	0.724	0.770	1.015	0.979
Beverly-Salem	0.934	0.898	0.881	0.835	0.663	0.496	0.611	0.661	0.639	0.827	0.586	0.390	0.509	0.898	0.840
Boston Harbor	---	---	---	1.108	1.254	1.096	1.058	1.057	1.123	1.224	1.160	0.734	0.750	0.725	0.626
Cape Cod Bay	0.710	0.776	0.680	0.479	0.716	0.822	0.533	0.752	0.539	0.630	0.693	0.567	0.494	1.052	0.906
Outer Cape Cod	0.808	0.824	0.765	0.598	0.856	0.811	0.937	0.861	0.923	1.219	1.148	1.339	1.021	1.105	1.117
Buzzards Bay	0.611	0.571	1.110	0.870	0.953	0.907	0.952	1.064	0.934	0.598	0.575	0.817	0.834	0.852	0.893

Table 2. CTHSOD, by state and region, for all sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1995.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
State	0.580	0.672	0.718	0.521	0.647	0.700	0.578	0.569	0.695	0.716	0.665	0.465	0.542	0.402	0.410
Cape Ann	0.067	0.109	0.586	0.450	0.395	0.474	0.417	0.388	0.670	0.589	0.728	0.726	0.447	0.658	0.800
Beverly-Salem	0.708	0.711	1.263	0.948	0.833	0.801	0.863	0.353	0.780	0.408	0.324	0.411	0.406	0.314	0.334
Boston Harbor	---	---	---	0.901	1.162	1.138	1.156	0.639	0.966	1.103	0.924	0.839	0.800	0.690	0.782
Cape Cod Bay	0.710	1.013	0.639	0.322	0.594	0.551	0.371	0.438	0.595	0.727	0.716	0.298	0.436	0.313	0.307
Outer Cape Cod	0.037	0.024	0.038	0.033	0.035	0.027	0.088	0.064	0.066	0.078	0.077	0.088	0.075	0.045	0.060
Buzzards Bay	0.787	0.620	0.638	0.785	0.848	1.312	0.871	1.153	1.188	1.236	1.072	0.784	1.156	0.649	0.492

Table 3. CTHAUL, by state and region, for all sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1995.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
State	1.473	1.401	1.624	1.389	1.708	1.899	1.873	1.738	2.297	2.216	1.996	1.460	1.720	1.389	1.457
Cape Ann	0.256	0.199	1.044	0.909	1.031	1.126	1.143	1.062	1.765	1.782	1.783	1.661	1.562	1.725	2.323
Beverly-Salem	1.855	1.713	2.526	2.504	2.567	2.435	3.482	1.862	3.477	1.867	1.563	1.502	1.540	1.717	1.920
Boston Harbor	---	---	---	2.773	3.038	3.314	3.334	1.959	3.104	3.382	2.451	2.069	2.284	2.189	2.390
Cape Cod Bay	1.544	1.680	1.345	0.825	1.337	1.512	1.031	1.442	1.742	1.921	2.086	1.065	1.334	1.033	1.102
Outer Cape Cod	0.233	0.145	0.210	0.189	0.160	0.161	0.324	0.353	0.306	0.453	0.452	0.490	0.474	0.288	0.359
Buzzards Bay	2.381	1.916	2.316	1.965	2.452	3.118	3.090	3.722	3.984	3.994	3.181	2.602	3.501	2.179	1.599

Table 4. Percent of females ovigerous, by state and region, for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1995.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
State	5.9	7.7	10.9	9.1	8.6	9.1	9.2	8.8	10.0	10.9	9.8	11.9	14.3	10.7	14.1
Cape Ann	1.7	3.1	4.4	3.2	4.6	5.0	4.5	3.5	6.3	6.9	4.3	6.7	9.3	4.7	5.3
Beverly-Salem	1.7	2.8	1.2	0.4	1.9	1.1	1.8	1.5	1.6	1.8	3.2	3.9	5.4	2.3	6.3
Boston Harbor	---	---	---	1.4	1.2	2.0	1.7	2.0	2.1	2.7	2.8	3.0	4.4	4.7	5.0
Cape Cod Bay	3.9	3.1	3.7	3.1	3.2	2.1	3.9	2.9	3.0	3.3	5.4	6.8	6.8	7.4	10.2
Outer Cape Cod	11.1	23.0	30.3	26.8	22.3	28.9	16.9	21.4	27.4	24.5	18.3	27.7	26.8	27.3	34.4
Buzzards Bay	16.0	16.9	32.5	26.6	25.0	25.3	31.0	27.8	29.2	35.0	28.2	28.8	40.9	22.1	26.0

Table 5. CTHSOD, by state and region, for all ovigerous female American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1995.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
State	0.024	0.027	0.050	0.035	0.044	0.057	0.049	0.034	0.057	0.073	0.032	0.054	0.091	0.036	0.045
Cape Ann	0.002	0.011	0.024	0.015	0.016	0.017	0.016	0.010	0.037	0.035	0.024	0.050	0.038	0.024	0.030
Beverly-Salem	0.011	0.009	0.008	0.003	0.011	0.004	0.010	0.004	0.009	0.005	0.008	0.014	0.020	0.008	0.017
Boston Harbor	---	---	---	0.009	0.007	0.015	0.012	0.012	0.010	0.028	0.017	0.017	0.026	0.024	0.028
Cape Cod Bay	0.020	0.025	0.016	0.009	0.015	0.010	0.012	0.009	0.014	0.017	0.028	0.016	0.023	0.022	0.034
Outer Cape Cod	0.012	0.028	0.040	0.030	0.038	0.032	0.034	0.030	0.043	0.055	0.038	0.076	0.053	0.046	0.081
Buzzards Bay	0.079	0.053	0.230	0.183	0.193	0.297	0.234	0.289	0.270	0.349	0.073	0.197	0.446	0.110	0.088

Table 6. CTHAUL, by state and region, for all ovigerous female American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1995.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
State	0.073	0.078	0.179	0.116	0.134	0.167	0.143	0.139	0.211	0.282	0.140	0.227	0.319	0.143	0.209
Cape Ann	0.010	0.016	0.038	0.027	0.039	0.047	0.048	0.031	0.096	0.109	0.056	0.088	0.135	0.064	0.085
Beverly-Salem	0.025	0.033	0.016	0.006	0.033	0.018	0.036	0.021	0.039	0.023	0.049	0.047	0.067	0.048	0.106
Boston Harbor	---	---	---	0.030	0.025	0.050	0.037	0.038	0.043	0.075	0.064	0.046	0.081	0.088	0.100
Cape Cod Bay	0.048	0.048	0.040	0.024	0.040	0.031	0.038	0.034	0.039	0.055	0.091	0.056	0.078	0.075	0.128
Outer Cape Cod	0.081	0.178	0.242	0.170	0.176	0.225	0.157	0.198	0.258	0.342	0.251	0.453	0.317	0.306	0.514
Buzzards Bay	0.243	0.139	0.828	0.515	0.555	0.748	0.889	0.929	0.953	1.291	0.359	0.847	1.438	0.383	0.343

Table 7. Estimated fishing pressure index, by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1995.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
State	86	87	86	86	88	88	89	90	88	87	89	89	90	88	86
Cape Ann	91	92	87	89	87	87	88	90	84	81	90	87	83	86	88
Beverly-Salem	89	92	94	88	96	96	97	98	96	95	97	98	96	96	95
Boston Harbor	---	---	---	93	94	96	96	96	96	95	96	95	96	95	94
Cape Cod Bay	90	93	92	94	93	94	92	94	94	93	91	92	94	90	86
Outer Cape Cod	46	43	42	38	48	46	54	57	47	50	54	57	60	60	55
Buzzards Bay	98	96	96	94	96	97	97	97	95	94	95	97	97	98	96

Table 8A. Total instantaneous (Z)* and total annual (A)** mortality estimates (Gulland, 1969) of American lobster by state and region, Massachusetts coastal waters, 1981-1995.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
State	1.58 *	1.72	1.66	1.66	1.76	1.80	1.90	1.86	1.80	1.76	1.90	1.92	1.86	2.02	1.83
	79% **	82%	81%	81%	83%	84%	85%	84%	83%	83%	85%	85%	84%	87%	84%
Cape Ann	1.65	2.18	1.72	1.92	1.94	2.03	1.85	1.75	1.55	1.39	1.97	1.87	1.51	1.81	1.95
	81%	89%	82%	85%	86%	87%	84%	83%	79%	75%	86%	85%	78%	84%	86%
Beverly-Salem	1.97	2.15	2.41	2.71	3.64	3.60	3.49	3.31	3.59	2.81	3.49	3.12	2.62	3.34	3.1
	86%	88%	91%	93%	97%	97%	97%	96%	97%	94%	97%	96%	93%	96%	95%
Boston Harbor	---	---	---	2.52	3.59	2.60	2.77	2.86	2.96	3.00	3.40	3.54	3.26	3.21	2.87
	---	---	---	92%	97%	93%	94%	94%	95%	95%	97%	97%	96%	96%	94%
Cape Cod Bay	2.53	2.69	2.42	2.52	2.31	2.83	2.26	2.74	2.43	2.46	2.33	2.58	2.60	3.10	2.35
	92%	93%	91%	92%	90%	94%	90%	94%	91%	91%	90%	92%	93%	95%	90%
Outer Cape Cod	0.43	0.46	0.42	0.33	0.52	0.51	0.80	0.71	0.62	0.63	0.77	0.78	0.87	0.92	0.74
	35%	37%	34%	28%	41%	40%	55%	51%	46%	47%	54%	54%	58%	60%	52%
Buzzards Bay	3.02	3.00	8.64	3.14	3.55	3.71	3.48	3.18	3.13	2.60	3.50	3.81	3.03	3.58	3.34
	95%	95%	99%	96%	97%	98%	97%	96%	96%	93%	97%	98%	95%	97%	96%

Table 8B. Total instantaneous (Z)* and total annual (A) mortality estimates (Beverton and Holt, 1956) of American lobster by state and region, Massachusetts coastal waters, 1981-1995.**

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
State	1.35 *	1.45	1.39	1.41	1.47	1.49	1.54	1.56	1.53	1.50	1.73	1.70	1.79	1.67	1.57
	74% **	77%	75%	76%	77%	78%	79%	79%	78%	78%	82%	82%	83%	81%	79%
Cape Ann	1.32	1.39	1.35	1.52	1.33	1.32	1.39	1.51	1.27	1.66	1.77	1.57	1.38	1.48	1.62
	73%	75%	74%	78%	74%	73%	75%	78%	72%	81%	83%	79%	75%	77%	80%
Beverly-Salem	1.59	1.70	1.85	1.78	1.96	1.99	2.16	1.98	2.01	1.83	2.29	2.50	2.23	2.18	2.09
	80%	82%	84%	83%	86%	86%	88%	86%	87%	84%	90%	92%	89%	89%	88%
Boston Harbor	---	---	---	1.82	1.75	1.92	1.88	1.84	1.94	1.87	2.19	2.14	2.33	2.28	2.09
	---	---	---	84%	83%	85%	85%	84%	86%	85%	89%	88%	90%	90%	88%
Cape Cod Bay	1.64	1.92	1.72	2.07	1.88	1.92	1.78	1.87	1.97	1.95	1.96	2.01	2.14	1.93	1.65
	81%	85%	82%	87%	85%	85%	83%	85%	86%	86%	86%	87%	88%	86%	81%
Outer Cape Cod	0.54	0.55	0.53	0.52	0.57	0.55	0.66	0.66	0.62	0.63	0.71	0.72	0.78	0.79	0.72
	42%	42%	41%	41%	43%	42%	48%	48%	46%	47%	51%	51%	54%	55%	51%
Buzzards Bay	2.97	2.53	2.26	2.21	2.36	2.41	2.36	2.35	2.14	2.27	3.08	2.70	3.11	2.85	2.44
	95%	92%	90%	89%	91%	91%	91%	94%	88%	90%	95%	93%	96%	94%	91%

Table 9. Instantaneous fishing mortality estimates (F), by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1995.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
State	1.14	1.21	1.17	1.19	1.25	1.28	1.32	1.36	1.36	1.32	1.43	1.44	1.48	1.41	1.32
Cape Ann	1.33	1.47	1.11	1.33	1.28	1.22	1.30	1.37	1.12	1.04	1.50	1.32	1.14	1.25	1.36
Beverly-Salem	1.42	1.47	1.64	1.68	1.81	1.93	1.89	2.02	1.95	1.86	2.08	2.16	1.96	1.94	1.88
Boston Harbor	---	---	---	1.77	1.70	1.80	1.87	1.83	1.94	1.86	2.01	1.97	1.97	1.90	1.85
Cape Cod Bay	1.53	1.60	1.58	1.73	1.59	1.70	1.56	1.70	1.82	1.72	1.66	1.71	1.85	1.66	1.47
Outer Cape Cod	0.47	0.48	0.45	0.42	0.47	0.47	0.57	0.53	0.54	0.51	0.59	0.61	0.65	0.68	0.62
Buzzards Bay	2.32	2.13	1.94	1.80	2.04	2.11	2.08	2.06	1.95	1.97	2.34	2.26	2.39	2.31	2.05

Table 10. Estimated exploitation rate (u), by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1995.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
State	0.62	0.64	0.63	0.64	0.65	0.66	0.68	0.69	0.69	0.69	0.68	0.69	0.69	0.68	0.66
Cape Ann	0.74	0.80	0.61	0.68	0.71	0.67	0.70	0.71	0.63	0.51	0.70	0.67	0.62	0.65	0.67
Beverly-Salem	0.71	0.71	0.75	0.79	0.79	0.83	0.77	0.88	0.76	0.85	0.82	0.79	0.78	0.79	0.79
Boston Harbor	---	---	---	0.82	0.81	0.80	0.84	0.84	0.86	0.85	0.82	0.81	0.76	0.75	0.78
Cape Cod Bay	0.75	0.71	0.75	0.73	0.72	0.75	0.73	0.77	0.79	0.76	0.73	0.74	0.76	0.74	0.72
Outer Cape Cod	0.37	0.37	0.35	0.33	0.36	0.36	0.41	0.38	0.40	0.38	0.42	0.44	0.45	0.47	0.44
Buzzards Bay	0.74	0.78	0.77	0.72	0.79	0.80	0.80	0.82	0.80	0.78	0.72	0.78	0.74	0.76	0.76

Table 11. Mean carapace length (mm), by state and region, for all marketable American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1995.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
State	88.5	87.9	88.1	88.2	87.8	87.6	87.5	88.2	88.9	89.0	88.7	88.8	88.4	88.8	89.2
Cape Ann	88.6	88.3	88.3	87.9	88.4	88.3	88.0	88.3	89.3	90.3	88.4	88.8	89.6	89.6	88.7
Beverly-Salem	87.6	87.0	86.6	86.9	86.2	86.2	85.8	87.1	87.7	88.3	87.5	87.2	87.5	87.8	88.0
Boston Harbor	---	---	---	86.8	86.9	86.4	86.6	87.5	88.0	88.1	87.8	87.9	87.5	87.5	88.0
Cape Cod Bay	87.2	86.4	86.9	86.1	86.4	86.3	86.7	87.3	87.7	87.7	88.1	88.2	87.7	88.3	89.2
Outer Cape Cod	98.2	97.5	97.4	99.7	97.0	96.3	94.6	95.2	96.5	96.1	95.3	95.2	93.8	94.2	94.2
Buzzards Bay	84.7	85.2	85.7	85.8	85.2	85.3	85.3	86.1	87.4	87.0	86.4	86.9	86.5	86.5	87.4

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Table 12. Mean carapace length (mm), by state and region for all sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1995.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
State	75.8	76.0	76.2	76.4	76.3	76.2	76.3	76.6	77.5	77.8	76.7	76.8	76.9	77.5	77.8
Cape Ann	78.0	77.7	77.5	77.3	77.6	77.1	75.9	77.0	78.3	78.8	78.7	77.9	78.3	78.0	77.2
Beverly-Salem	74.3	76.5	74.9	76.1	75.9	74.7	74.7	74.5	76.4	76.1	73.4	73.5	75.1	75.8	76.2
Boston Harbor	---	---	---	77.1	76.9	76.9	76.5	75.6	76.8	77.4	75.4	74.6	75.3	76.0	77.3
Cape Cod Bay	76.6	76.4	76.7	75.6	76.1	76.2	75.6	76.9	77.9	77.8	77.4	76.8	76.7	78.6	78.6
Outer Cape Cod	75.9	76.2	77.1	75.1	76.6	75.9	77.0	77.1	76.8	78.8	78.8	79.0	79.4	78.3	80.0
Buzzards Bay	75.8	75.5	76.8	76.4	76.1	76.0	76.6	76.3	77.7	77.4	76.6	77.1	78.3	77.6	77.7

Table 13. Mean carapace length (mm) of all ovigerous female American lobster, by state and region, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1995.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
State	88.3	87.6	88.6	87.4	87.9	88.1	87.1	87.2	88.5	88.0	86.0	85.8	85.3	86.3	86.6
Cape Ann	109.0	100.3	94.3	90.5	93.8	95.0	91.6	94.0	100.4	95.1	91.7	91.9	91.0	92.7	93.3
Beverly-Salem	80.5	84.5	85.8	83.5	85.9	83.5	81.8	83.0	85.2	85.5	83.8	81.6	82.6	83.1	83.3
Boston Harbor	---	---	---	82.1	84.0	81.3	82.3	83.7	83.0	83.8	82.0	82.0	80.8	80.9	81.5
Cape Cod Bay	86.4	83.8	85.5	84.4	85.2	86.8	87.0	84.7	86.1	85.0	83.9	84.1	83.0	84.8	85.2
Outer Cape Cod	109.8	106.1	108.0	107.1	106.9	107.3	102.5	105.2	105.4	104.6	101.9	99.2	100.7	100.0	100.6
Buzzards Bay	78.1	79.6	81.6	83.0	80.1	79.4	80.2	80.6	81.3	80.8	79.8	79.9	81.0	81.5	81.8

Table 14. Cull rate (percent), by state and region, for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1995.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
State	10.0	10.8	10.7	14.9	18.1	20.9	17.0	18.2	19.2	18.6	18.1	18.5	20.3	21.0	22.0
Cape Ann	10.0	9.8	10.5	11.5	23.9	25.3	20.2	21.2	16.7	16.7	19.7	18.2	19.2	17.1	19.6
Beverly-Salem	8.3	8.6	10.2	20.9	23.0	30.0	24.1	26.3	28.6	27.3	28.9	22.7	28.3	30.8	25.1
Boston Harbor	---	---	---	13.3	19.3	19.1	16.9	16.3	13.8	14.7	13.5	17.2	23.4	23.0	22.2
Cape Cod Bay	11.1	10.7	10.9	15.6	18.3	21.6	16.2	17.4	22.8	20.5	18.9	18.3	18.1	19.4	21.5
Outer Cape Cod	5.7	11.3	8.9	13.0	13.4	16.1	12.6	15.0	14.0	15.5	13.2	15.7	17.3	20.1	19.0
Buzzards Bay	13.5	14.7	12.4	12.4	13.4	14.6	15.1	15.6	12.6	13.6	13.9	19.3	20.5	24.0	24.4

Table 15. Cull rate (percent), by state and region, for all legal-sized American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1995.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
State	8.1	9.4	9.2	12.9	14.8	17.1	14.7	15.7	14.9	15.1	15.0	17.1	17.4	21.2	20.9
Cape Ann	10.7	9.6	7.5	10.4	19.4	20.3	18.0	19.3	13.9	13.7	16.8	18.3	16.3	16.5	16.2
Beverly-Salem	4.3	7.7	7.4	15.5	19.3	22.1	17.1	21.4	18.7	25.6	22.8	19.9	24.6	25.4	18.8
Boston Harbor	---	---	---	10.1	16.2	15.8	12.9	13.1	9.9	9.9	12.3	14.0	17.5	18.0	20.1
Cape Cod Bay	9.3	9.3	10.0	13.2	14.5	18.1	15.0	15.6	12.0	16.3	17.8	16.8	16.3	21.7	23.3
Outer Cape Cod	5.3	10.3	8.1	13.3	12.5	14.9	13.1	14.3	13.3	14.1	12.8	15.3	16.4	19.9	18.3
Buzzards Bay	16.1	13.2	12.7	12.3	13.8	13.6	15.2	14.1	12.6	12.6	11.5	22.2	18.9	23.5	22.6

Table 16. Cull rate (percent), by state and region, for marketable American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1995.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
State	8.2	9.1	9.2	13.2	16.2	17.6	15.7	16.0	15.4	15.6	16.1	17.6	17.6	21.9	21.5
Cape Ann	10.8	9.8	7.3	10.5	20.9	20.7	18.4	19.9	14.0	14.2	16.8	18.1	13.7	16.7	16.0
Beverly-Salem	4.4	8.0	7.4	15.6	18.5	22.2	17.2	21.3	18.9	23.8	23.1	20.0	24.7	25.5	19.0
Boston Harbor	---	---	---	10.2	16.2	15.7	12.8	13.1	9.9	9.9	12.4	14.0	17.5	18.0	20.1
Cape Cod Bay	9.3	9.3	10.0	13.2	15.9	18.2	14.8	15.6	19.1	16.2	17.8	16.7	16.2	22.3	23.3
Outer Cape Cod	5.3	10.9	8.6	14.8	12.9	16.8	13.2	14.9	13.9	14.6	14.1	16.8	17.3	21.6	20.4
Buzzards Bay	16.9	13.1	12.3	12.6	15.4	14.1	15.4	14.7	13.0	12.4	11.7	22.5	19.4	23.7	23.0

Table 17. Cull rate (percent), by state and region, for sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1995.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
State	11.2	11.5	11.6	16.1	20.2	23.2	18.2	19.6	21.1	20.2	19.2	19.3	21.8	22.5	22.9
Cape Ann	8.0	10.6	12.6	12.2	26.9	28.7	21.5	22.1	17.9	18.3	21.0	18.2	20.9	17.4	21.2
Beverly-Salem	10.0	9.0	11.2	22.3	24.0	31.8	25.3	28.6	30.8	29.2	31.6	23.5	29.5	33.8	28.2
Boston Harbor	---	---	---	14.5	20.5	20.0	18.0	18.0	15.2	16.4	13.9	18.3	25.3	24.7	22.8
Cape Cod Bay	11.9	11.3	11.4	17.0	20.2	23.4	16.8	18.3	24.0	21.8	19.2	19.0	18.8	17.8	20.1
Outer Cape Cod	7.8	17.9	13.5	11.7	18.6	22.8	11.0	16.9	17.1	20.7	14.3	17.1	20.2	21.3	21.8
Buzzards Bay	12.7	15.2	12.2	12.4	13.3	14.9	15.0	16.2	12.6	13.9	14.5	18.3	21.0	24.2	25.6

Table 18. Percent trap mortality by state and region for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1995.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
State	0.15	0.04	0.22	0.15	0.18	0.20	0.10	0.15	0.12	0.17	0.37	0.08	0.13	0.22	0.21
Cape Ann	0.00	0.00	0.09	0.27	0.03	0.16	0.00	0.03	0.13	0.09	0.48	0.10	0.11	0.14	0.28
Beverly-Salem	0.00	0.00	0.00	0.00	0.04	0.22	0.03	0.19	0.14	0.29	0.41	0.13	0.19	0.13	0.74
Boston Harbor	---	---	---	0.00	0.03	0.03	0.23	0.09	0.03	0.04	0.01	0.03	0.06	0.04	0.01
Cape Cod Bay	0.00	0.02	0.03	0.00	0.00	0.02	0.15	0.00	0.02	0.05	0.02	0.02	0.02	0.00	0.03
Outer Cape Cod	0.46	0.22	0.23	0.48	0.40	0.85	0.27	0.66	0.47	0.62	0.35	0.24	0.30	0.58	0.38
Buzzards Bay	0.62	0.00	1.13	0.43	0.76	0.25	0.01	0.18	0.11	0.18	1.74	0.10	0.29	0.71	0.16